GIS MODELLING IN THEMATIC MAPPING OF LAND COVER CHANGES IN THE FOREST-STEPPE REGION OF RUSSIA

ELIZAVETA KHAZIEVA *

Key-words: GIS, remote sensing data, forest-steppe region, thematic maps, land cover, Russia.

Abstract. Nowadays there are many remote sensing methods and tools, which help to deeply understand the land cover processes on the large area without field researches. The cartographic modeling is one feasible way to analyze and deeply understand the data and processes which take place in the region. A combination of different data (such as remote sensing data, statistical information, historical maps and others), a knowledge of the territory ensures integral investigation, and a better demonstration of the result. There are many different approaches and models, one of them being thematic cartography. This is part of cartography focusing on natural phenomena, social, political and economic issues, combining visualization and exploration methods, and targeting and supporting different groups of users (Tikunov, 1997). Models are useful and used in a vast array of GIS applications, from simple evaluation to the prediction of future landscapes. Cartographic modelling is a general methodology for the analysis and synthesis of geographical data. It employs what amount to an algebra in which single-factor maps are treated as variables that can be flexibly manipulated using an integrated set of functions (Paul *et. al.*, 1991). The main trends of landscape changes is croplands decreasing especially in the 1990s, the situation beginning to improve by 2000 – 2006s. It probably has to do with the reforming procedure which had been started since the 1900s. Around 2000, the economic situation in Russia had stabilized again (Ioffe *et al.*, 2008). For a better understanding of the impacts caused by political and economic developments on land use, further studies are necessary. The developed model has to be amended by adding some socio-economic data. It would help to better understand the process in a particular area and would allow to emphasize the drivers of changes more precisely.

1. INTRODUCTION

To understand recent changes in the Earth's system and provide adequate policy advice, quantitative and spatially explicit data and models are needed on how land cover has been changed by mankind and how it will be changed. The changes in land cover and land use are a significant cause of global change, it is an essential component of all considerations of sustainability (Geist, 2008).

Nowadays there are many remote sensing methods and tools, which help us to deeply understand the land cover processes on a large area without field researches. The cartographic modeling is one feasible way to analyze and deeply understand the data and processes which take place in the region. A combination of different data (such as remote sensing data, statistical information, historical maps and others), a knowledge of the territory ensures integral investigation, and a better demonstration of the result. The possibility of GIS modeling can be used to predict their behavior and performance changes. Consequently, it allows researches and persons in charge to protect and manage the area, and assures prompt reaction to the changes.

There are many different approaches and models, one of them being thematic cartography. This is part of cartography focusing on natural phenomena, social, political and economic issues, combining visualization and exploration methods, and targeting and supporting different groups of users (Tikunov, 1997).

During the last century, a significant expansion of agricultural activity, urbanization and industrialization might be observed (Moran *et al.*, 2004, EEA, 2005). The forest-steppe of the European part of Russia is the area of high human interference with natural processes in the

* PhD student, Moscow State University, Faculty of Geography, Leninskye Gori, 1 Moscow, Russia, saviliz@yandex.ru.

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landscapes. Therefore, it is necessary to observe the natural aspects and human activity as a united, inseparable system.

2. DATA AND METHODS

Landscapes are complex, spatially heterogeneous systems with many properties and values: this makes classification and mapping difficult, especially at regional scales (Mucher *et al.*, 2010).

Based on the method of interpretation of landscape as function of different factors which include climate, geology and geomorphology, soils, vegetation and so on, it is possible to obtain the integrated data base of landscape characteristics.

We aimed to observe the land use/landscape change from 1981 to 2006 for the forest-steppe region. Then, using these data source as a land cover change information with the other variety of data related to the natural aspects we suggested to develop the integrated GIS model for the spatial identification and analysis of land cover dynamic. Remote sensing provides excellent methods for this objective, especially with regard to a large area such as the forest-steppe region in Russia (the approximate area is 400 000 sq. km).

For the spatial modeling of landscapes and habitats the Geographic Information System (GIS) combined with remote sensing approaches and available environmental data sets should be used. Burrough and McDonnel (1998) define GIS as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes. Remote sensing is strongly related to GIS, since it is the science of obtaining information about an object, an area or phenomenon through the analysis of data acquired by a device that is not contact with the object or phenomenon under investigation (Lillesand *et al.*, 2008).

The different data sources have been used for the development of an integrated model, including climate data, soils, etc. (Table 1). In order to achieve the homogeneity of the variety of data a preprocessing should be fulfilled. In this case, we used the data sets for 1981, 1990, 2000 and 2006 derived from The Global Inventory Modelling and Mapping Studies (GIMMS) as a retrospective type of information. This is a global measure of normalized difference vegetation index (NDVI) covering a 22-year period. The GIMMS data set was originally generated to characterize biophysical change as defined in the International Satellite Land Surface Climatology Project (ISLSCP) Initiative II collection. NDVI, in general, is a vegetation index used in climate models and biogeochemical models to calculate photosynthesis, the exchange of CO_2 between the atmosphere and the land surface, land-surface evapotranspiration and the absorption and release of energy by the land surface (Tucker *et al.*, 2004). This data set provides improved results based on corrections for calibration, view geometry, volcanic aerosols, and other effects not related to actual vegetation change. Data published in 2004 by a group of authors (Tucker, Compton, Pinzon, Jorge, Brown, Molly) and supported by the University of Maryland, USA, who also owns the copyright to the data. The horizontal resolution of these data sets varies depending on the area, in our case we have approximately 5 kilometers resolution.

There are only few datasets for the whole territory describing land cover: the Land Cover Map of Northern Eurasia. It represents the spatial distribution of the major vegetated and non-vegetated land cover types for the year 2000. Another one is the Global Land Cover Classification derived from AVHRR sensor and afterwards analyzed and improved using different additional information. In our case, we considered the data derived from The Global Land Cover Facility project (for 1992-1993) as a model of land cover classification. This global land cover products are much finer in resolution and classification. More than 200 high resolution scenes are used for land cover type confirmation. Most of the scenes used were acquired by the Landsat Multispectral Scanner System (MSS), and a few by Landsat Thematic Mapper and the LISS (Linear Imaging Self-Scanning Sensor). These data sets have 1 kilometers resolution. Scenes were considered unsuitable if haze or poor quality data obscured the scene, or if the cover types in the scene could not be visually distinguished (Boriah *et al.*, 2008). For most scenes, the project member aimed to identify only one cover type within the scene. It was possible, however, to identify more than one cover type in some scenes if croplands were visually identifiable based on the spatial patterns of fields or if vegetation maps showed the presence of clearly identifiable cover types (Hansen *et al.*, 2000). As an integral part of the GIS model the climate data should be included. In this case the four monthly variables: average minimum, mean, and maximum temperature and precipitation were implemented into the procedure. The data were compiled using monthly averages of climate as measured at weather stations from a large number of global, regional, national, and local sources, mostly for the 1950–2000 period. We interpolated these data using the thin-plate smoothing spline algorithm implemented in ANUSPLIN (Hutchinson, 2004). Then the data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (Hijmans *et al.*, 2005). As long as we considered the pragmatic approach (Mucher *et al.*, 2006), which led to the selection of different key data sources for identifying and delineating landscape units, the FAO soil database had been taken into account. This database provides information on the soil unit composition for each of the 15,773 soil mapping units. The database shows the composition of each soil mapping unit, and standardized soil parameters for top- and subsoil. A soil mapping unit can have up to 9 soil unit/topsoil texture combination records in the database.

Using Explicit Cross Tabulation function in GeoMedia Product (Intergraph Corp.) we have obtained the GIMMS images classified with GLCF parameters (Fig. 1). Afterwards it was possible to apply the schema of transformation to the four NDVI data sets. Consequently, land cover images for four periods of time (1981, 1992, 2000 and 2006) were derived.

Table 1

The data sources used in the research

Data	Description	Source
Land Cover information	Land Cover Classification by GLCF	http://www.landcover.org/data/landcover/
GIMMS data	Landsat	http://glcf.umd.edu/data/gimms/
DEMs (SRTM, ASTER)		https://lpdaac.usgs.gov/products/aster_products_table; http://earthexplorer.usgs.gov/;
Climate data	Temperature, precipitation (past, current, future)	http://www.worldclim.org/
	Temperature Anomalies	http://neo.sci.gsfc.nasa.gov/blog/2009/02/19/avg-lst-anomaly/
Soils		http://www.fao.org/nr/land/soils/harmonized-world-soil-database/download-data-only/ru/

There were four categories of landscape which were used:

1. Croplands: lands with > 80% of the landscape covered in crop-producing fields. Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.

2. Grasslands: lands with continuous herbaceous cover and < 10% tree or shrub canopy cover.

3. Wooded Grasslands/Shrublands: lands with herbaceous or woody understories and tree canopy cover of > 10% and < 40%. Trees exceed 5 m in height and can be either evergreen or deciduous.

4. Mixed Forests: lands dominated by trees with a per cent canopy > 60% and height exceeding 5 m. they consist of tree communities with interspersed mixtures or mosaics of needleleaf and broadleaf forest types. Neither type has < 25% or > 75% landscape coverage.

Spatio-temporal changes of land use analysis are significant for identifying dynamic changes in a certain period. The general analysis of the quantity, structure and environment of land-use change is useful to perceive the trend and character of land-use spatio-temporal change (Xin Chang *et al.*, 2008). The transformation of landscapes is an inevitable step of their development. Globally, land cover today is altered principally by direct human use: by agriculture and livestock raising, forest harvesting and management and urban and suburban construction and development (Meyer, 1995). Hence, in order to use land optimally, it is not only necessary to have the information on existing land use land cover, but also the capability to monitor the dynamics of land use resulting out of both changing demands of increasing population and forces of nature acting to shape the landscape. Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Change detection is an important process in monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution of the population of interest. Using the change detection methodology for images which reflect the land cover types for four periods we could obtain the image of the transformation types (Figs. 2, 3).

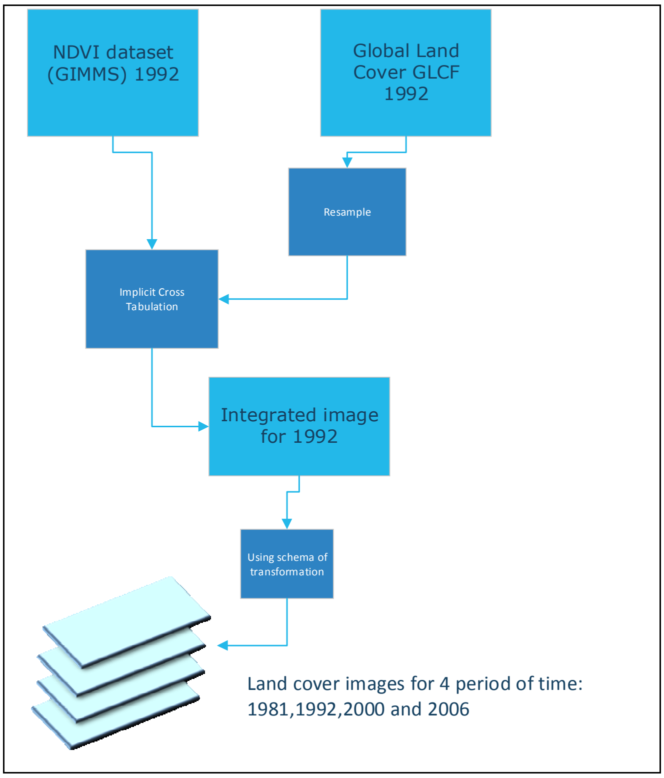

Fig. 1 – The schema of NDVI and GLCF data integration, preprocessing and analysis.

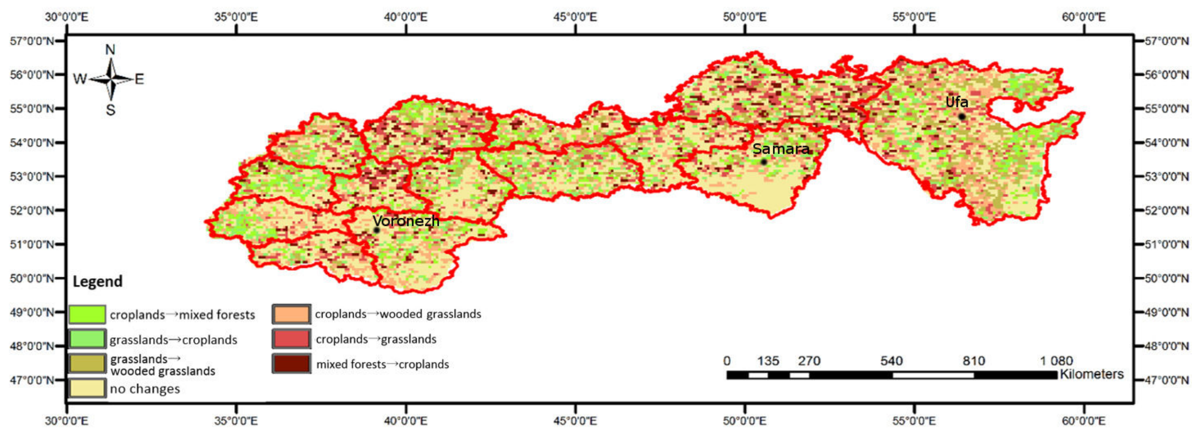

Fig. 2 – The variety of land cover types transformation (1981–2006).

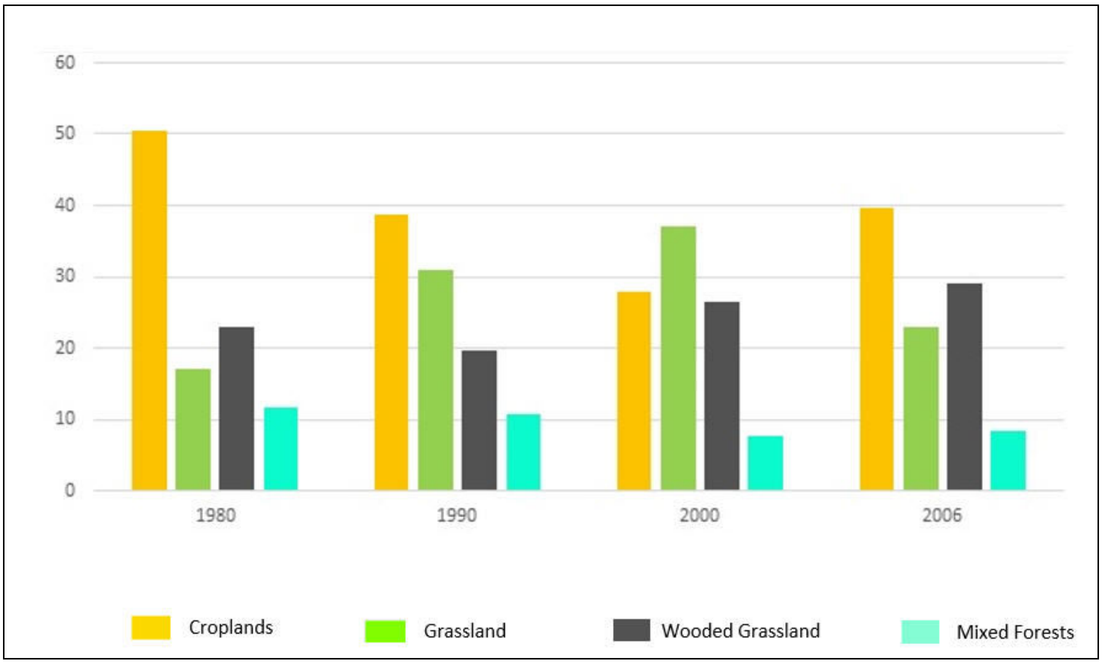

Fig. 3 – The distribution of prevailing land cover type (1980s–2006).

3. GIS MODELLING

Models are useful and used in a vast array of GIS applications, from simple evaluation to the prediction of future landscapes. Cartographic modelling is a general methodology for the analysis and synthesis of geographical data. It employs what amount to an algebra in which single-factor maps are treated as variables that can be flexibly manipulated using an integrated set of functions (Paul *et al.*, 1991). Generally, models are the sophisticated tools for characterizing and understanding environmental patterns and processes, and estimating the effects of environmental change at local, regional and global scales (Goodchild *et al*., 1993). Modelling of land use/cover and their changes depend on a variety of possible reasons. They could be roughly divided into two groups – the natural, biophysical conditions and the dominant socio-economic factors. However, at the regional scale the socio-economic assessment could hardly be implemented, socio-economic indicators should be evaluated for the local units. In our case, the kind of impact of human activity had been taken into account as part of land cover use data.

Thus, there were used different "natural" data for developing the model, including ratio temperature and precipitation, the relief information (slope, curvature, roughness and absolute elevation), type of land cover transformation and soils data set (Fig. 4).

Afterwards segmentation techniques (Burnett, Blaschke, 2003; Lucas *et al.*, 2007) were used for the spatial identification of the landscape units. Segmentation (object recognition, based on spatial characteristics) is the process of identifying spatial units, which are mostly derived from satellite imagery. Classification was subsequently based on statistics from the core of pixels at the center of each object, thereby avoiding mixed pixels from the margins (Briggs, 2003). In this particular case, the segmentation was based on the thematic data layers; the ratio of the temperature to the precipitation, soils, data derived from DEM and types of land cover changes.

Based on a variety of input datasets we have distinguished 10 classes that are characterized by a unique combination of all input parameters (Fig. 5, Table 2).

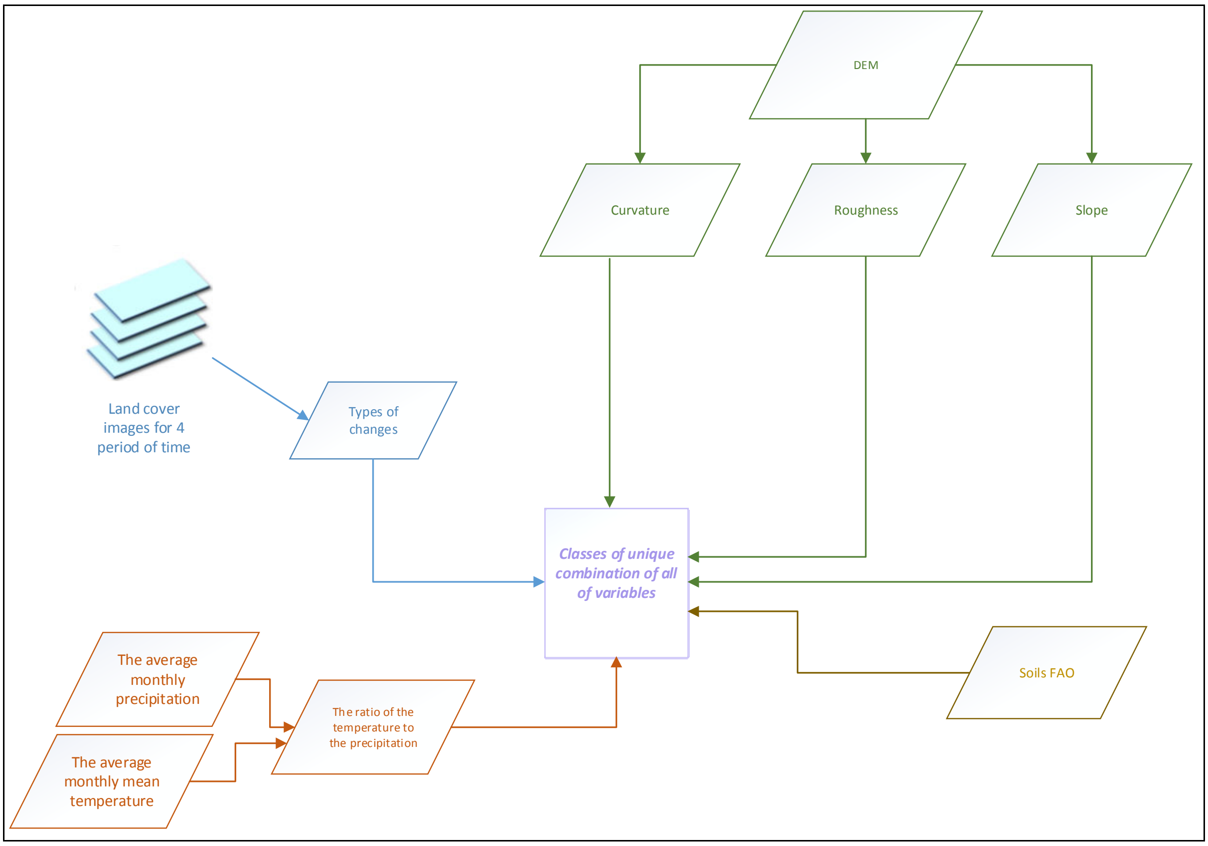

Fig. 4 – The integrated model of analysis of the input data.

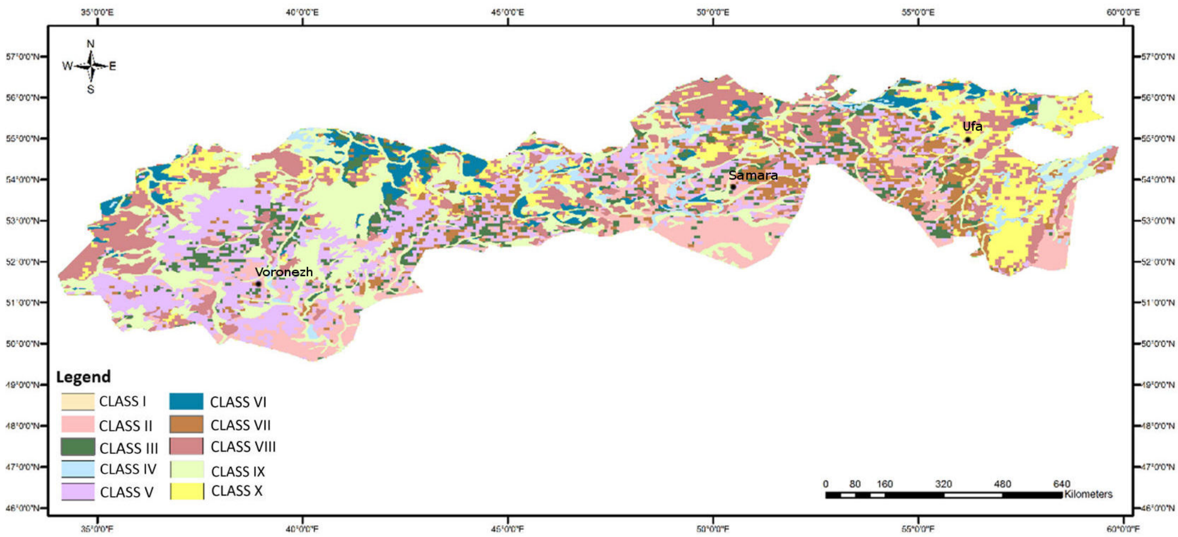

Fig. 5 – Thematic image of variables combination.

Table 2

The description of the landscape units with characteristics of input variables

Class	*Altitude (m)*	*Slope (°)*	*Soils*	*Temperature (°C) – average (spring –summer)*	*Precipitation (mm) average (spring –summer)*	*Prevalent type of land cover transformation*	*The share of the total area (%)*
I	100–150	1–2	Haplic Greyzems	18–20	60–70	croplands→ wooded grasslands	0,82
II	100–150	< 1	Haplic Chernozems	18–20	40–50	no changes	21,34
III	150–200	< 1	Luvic Phaeozems	16–18	60–70	croplands→ wooded grasslands	7,36
IV	0–50	< 1	Haplic Greyzems	18–20	60–70	no changes	3,08
V	150–200	< 1	Luvic Phaeozems	18–20	60–70	croplands→ wooded grasslands	19,52
VI	100–150	2–4	Eutric Podzoluvisols	16–18	60–70	grasslands→ wooded grasslands	4,41
VII	150–200	1–2	Luvic Phaeozems	18–20	70–80	grasslands→ wooded grasslands	6,76
VIII	150–200	< 1	Haplic Greyzems	16–18	60–70	croplands→ grasslands	11,34
IX	150–200	< 1	Haplic Chernozems (along rivers – Eutric Fluvisols)	16–18	50–60	grasslands→ wooded grasslands	14,98
X	150–200	1–2	Haplic Greyzems	14–16	60–70	grasslands→ wooded grasslands	10,39

4. RESULTS AND CONCLUSIONS

The main trends of landscape changes are the croplands decreasing especially in 1990s, the situation begins to improve by 2000–2006s (Fig. 3). It probably has to do with the reforming procedure which had been started since 1900s. Up until that time, the land had been under federal ownership; now the farmers received a partial ownership, however, little change in land use followed: similar to the Soviet practice, Russia's agriculture is still dominated by the former collective farms. Around 2000 the economic situation in Russia was again stabilized (Ioffe *et al.*, 2008). So in 2001, the new Land Code came into force. The Land Code regulates the transfer of state-owned lands to private property. Furthermore, these drivers are steered by the social and economic transition: changes in ownership, stagnation of agriculture, re-industrialization, infrastructure development, and others (Milanova, 2012).

The whole area is being characterized with the process of overgrowth, nevertheless this tendency could be clearly observed in the west regions. The eastern part of the territory is characterized by conversion of croplands into grasslands and wooded grasslands. The croplands had been changed by wooded grasslands and shrublands, also the grasslands had given place to wooded grasslands. The first type of transformation is more related to the southern areas with higher temperature (spring-summer season), chernozems, and flatter slopes and, in general, lower altitude. Another one is more typical of the north and east-north part of the territory. These areas are characterized by lower temperature (spring-summer season), greyzems and haplic chernozems on the steeper slopes. For a better understanding of the impacts caused by political and economic developments on land use further studies are necessary. Different spatial levels of the LUCC study help providing an understandable presentation of the geographical distribution of areas with different LUCC trends and degree of land cover transformation. Thus, the investigation and GIS modeling analysis on different scales should be fulfilled. The developed model has to be amended by adding some socio-economic data. It would help to better understand the process in a particular area and would allow to emphasize the drivers of the changes more precisely.

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